Martian Dust Devil Exploration Simulator

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Abstract

The SENSORS project founded by Tufts University seeks to teach science and technology to students via the Internet using LEGO® robotics and the content of the United States National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) science missions. The Martian Dust Devil Exploration Simulator (MDDES) is the SENSORS site at the Jet Propulsion Laboratory. The project integrates many of the engineering disciplines with physics, math, geology and meteorology, making interdisciplinary connections using the context of the dust cycle on Mars. Students begin with simply observing and counting dust devils. More advanced students can create instrumentation, learn about the physics of dust devils, tornadoes and terrestrial and Martian weather. They can even explore the mathematics of dust devil formation. The MDDES also incorporates aspects of popular media, social studies, history, literature, agriculture and environmental conservation into the curriculum.

1. Introduction

The Martian Dust Devil Exploration Simulator (MDDES) is a project developed as a part of the SENSORS Project at Tufts University [1]. The SENSORS Project aims to

> "encourage and promote mathematics, robotics, engineering and earth and space science through telerobotics. The goal is to excite students about different remote environments by having the students explore the 'new worlds' through the Worldwide Web and LEGO® [robotics]"[1].

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The project is currently placing LEGO robots in NASA and other centers across the country to simulate for students the many different branches of science that use remote sensing and robotics technology for students. All of the SENSORS sites are connected to the Internet so that students far from NASA centers can participate in the SENSORS activities. Currently, SENSORS outreach sites are being developed at Tufts University, Marshall University, the Monterey Bay Aquarium, NASA Ames Research Center, NASA Goddard Space Flight Center, NASA Glenn Research Center, and the Jet Propulsion Laboratory (JPL) [2].

The MDDES is the SENSORS site currently under development at JPL and builds on JPL's involvement in the execution and planning of missions to Mars, such as the Viking landers, the Pathfinder mission, Mars Global Surveyor and currently, the Mars Odyssey Orbiter. Many of the instruments currently under construction at JPL are designed to learn more about the transport of dust on Mars. The simulations and curriculum generated by the MDDES project will incorporate science data and observations from these missions and make this data available to the public. Scientists and engineers from JPL and the Mars Program will be invited to participate.

The MDDES uses LEGO® robotics to simulate the exploration of Mars and the Martian dust cycle. The specific objectives of the MDDES are:

- To teach students about the phenomenon of dust devils which occur on both Earth and Mars and expose them to data on Martian dust devils collected by NASA and ESA.
- To teach students how to measure wind speed and direction as a function of time. These measurements will lead to the students learning how to measure the size, speed and direction of the dust devil itself.
- To teach students how to acquire, graph and interpret data. They will collect data from several instruments simultaneously and use it to draw conclusions about the size, speed and direction of the dust devil.
- To teach students how to construct an instrument for exploring the simulated Martian surface and measuring the velocity of dust devils using LEGO® Mindstorms® kits.
- To teach students interdisciplinary connections and build an appreciation of the Earth's meteorology through comparison with the meteorology of Mars.

2. Observing the Martian Dust Cycle

2.1 Dust Devils Defined

Dust devils are defined as "low pressure, warm-core vortices with typical surface diameters between 1 and 50 m" [3,4,5]. Thermodynamics drives the formation of dust devils and can explain many of their observed characteristics. Local wind shears give dust devils their vorticity, and they can rotate either cyclonically or anticyclonically with equal probability. Observations show that dust devils move with the speed of the ambient wind (typically 5 m/s) [6]. High wind environments produce larger diameter dust devils. Terrestrial dust devils are most commonly observed in hot desert regions, but have been observed in the subarctic as well [7]. Mars proves to be a good environment for the formation of dust devils due to its lower atmospheric pressure, higher winds, and prevalence of dust. Dust devils have been observed on Mars by the Viking Landers [8], Mars Pathfinder [9] and Mars Global Surveyor [10].

A simple scaling theory based on the heat engine framework proposed by Rennó, et al. (1998) can be used to describe the behavior of dust devils [6]. Near the surface, air parcels spiral in towards the moving core while absorbing heat from the surface. This theory suggests that the radius of a dust devil is determined by the initial angular momentum of the air parcels converging towards the center. This theory has been applied to dust devils in Arizona as well as dust devils observed by Mars Pathfinder with good success [11].

2.2 Observations of Dust Devils on Mars

Recent images from Mars Global Surveyor have shown just how prevalent dust devils can be on the surface of Mars (Figure 1) [12,13,14]. This dust poses a threat to both robotic missions and future human exploration of Mars. Dust devils may be the dominant mechanism by which dust is entrained in the Martian atmosphere [15]. Dust in the atmosphere reduces the amount of solar radiation that reaches photovoltaic energy systems on the Martian surface. Surfaces and moving parts will be especially susceptible to degradation by blowing dust. Electrical discharges are also expected to be a major concern due to the dry environment and strong winds. Electrostatic charge can build up because of the rubbing of particles against one another, a phenomenon also known as triboelectric charging. The charge buildup may be important for the understanding of material transport. Preliminary work on the saltation of terrestrial particles (both snow and sand) has shown that the force due to electric field is of the same order of magnitude as the force due to Earth's gravity [16]. Since gravity on Mars is less than that on Earth, electrical transport effects may dominate the effects due to gravity [10].

The simplest way to observe dust devils is just to watch and count them. Simple measurements such as the diurnal pattern of occurrence are important for understanding the amount of energy available for dust devil formation [6]. Pathfinder was able to "see" a dust devil in action in several different wavelengths of visible light [17,18]. Many instruments have been used to measure the various properties of dust devils, including pressure and temperature sensors, anemometers, accelerometers [9] and mobile Doppler radar [19]. Light detection and ranging (LIDAR) has also been proposed as a method of observing and tracking dust devils on Mars [10]. Proposals for future Mars exploration also include instruments for detecting the electrical fields generated by dust devils [20,21].

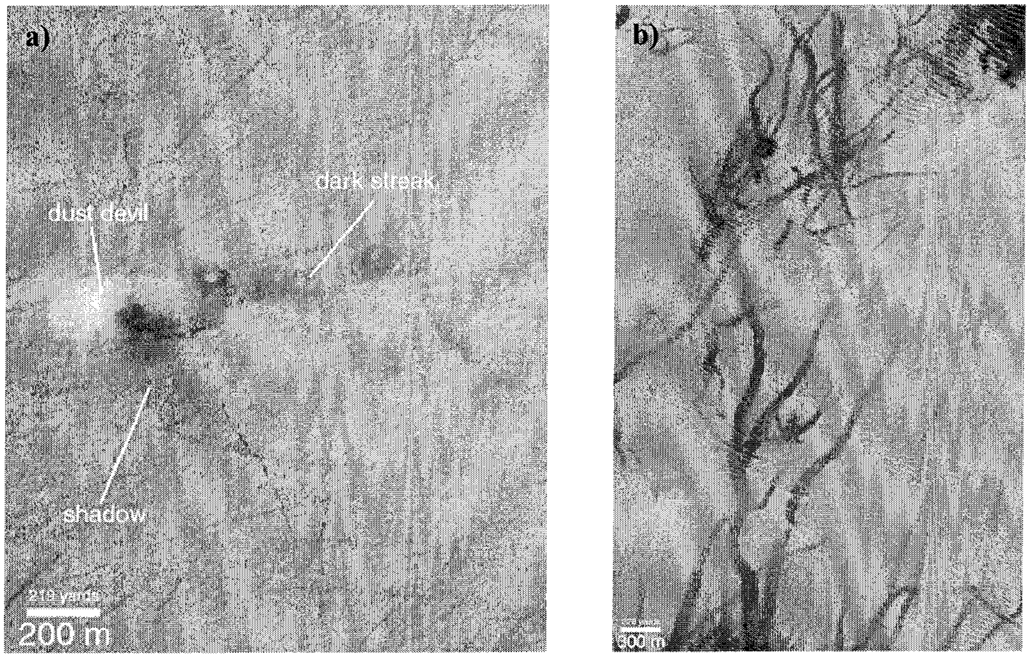

Figure 1. A Mars Global Surveyor Mars Observer Camera images taken over a) Promethei Terra, December 11 1999, showing a single active dust devil and b) Argyre Planitia, February 21, 2000, showing wild patterns of criss-crossing dark streaks believed to be caused by dust devils [13,14].

3. The Mars Dust Devil Exploration Simulator

The MDDES incorporates the current understanding of Martian dust devils in an effort to teach students about comparative planetary science, meteorology, physics and engineering. The simulator itself consists of four main parts: the rover, the landscape, the Web site and the curriculum.

3.1 The Rover

At the center of the MDDES is a rover constructed using the LEGO® Mindstorms™ line of products (Figure 2). The Robolab™ software [22] used for controlling the rover utilizes a special edition of LabVIEW™ [23] which has fewer options available and contains information specific to the LEGO® hardware as well as a unique user interface that is appropriate for children. The rover is equipped with a programmable LEGO® "brick" which processes commands from the server computer, collects data and controls the motion of the motors. The MDDES rover is the data collection tool for students and can be controlled via the Internet. Students log into a server computer and either use prewritten programs to take data or upload their own programs to control the rover and obtain data. The server schedules the use of the rover and downloads the selected Robolab™ program to the rover via an infrared port. The student scientists can collect wind speed and wind direction data through the wind vane and anemometer mounted on top of the rover tower.

Simplified anemometers and accelerometers have been constructed and integrated into the MDDES rover to allow students to observe the behavior and properties of simulated dust devils and generate graphs of the data similar to those obtained by the Mars Pathfinder Atmospheric Structure Investigation Meteorology (ASI/MET) experiment.

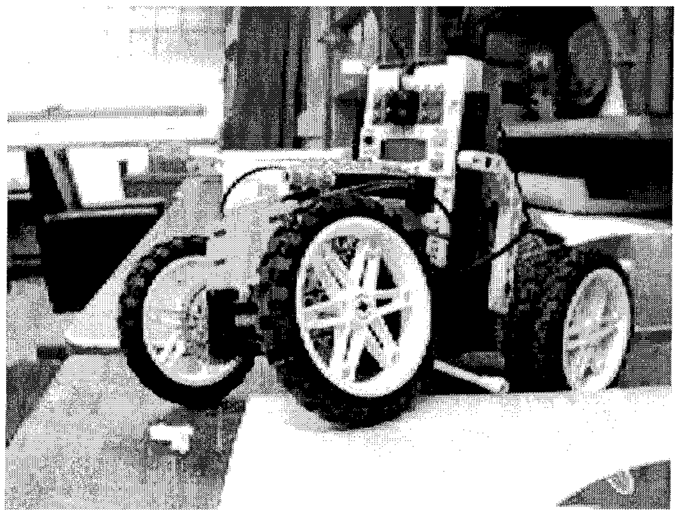

Figure 2. The Mars Dust Devil Exploration Simulator (MDDES) is constructed using the LEGO® DACTA™ line of products and controlled using Robolab™ software.

3.2 The Landscape

The MDDES rover is operated in a Martian landscape constructed from a combination of wire mesh and papîer maché (Figure 3). This workspace is roughly 16 feet square, allowing ample room for rover operations. Located on the perimeter is a large box fan to provide ambient wind. On the ceiling above the landscape is a small oscillating vortex fan, which provides a very simple way of simulating dust devils. The location of the dust devil fan is changed frequently, and may be automated in the future. A Web-enabled camera located above the landscape provides an overhead view of the site, which is illuminated with four bright incandescent lamps to provide the best possible imaging conditions.

3.3 The Web site

The MDDES Web site (Figure 4) provides the user interface for the rover and landscape. Through the Web site, students can see live images of the rover and landscape, download prewritten programs to use with rovers in their classrooms, select prewritten programs to be run on the MDDES rover, submit their own programs and view the data collected during their missions. The Web site also hosts the MDDES curriculum for both students and teachers. The Web site may eventually be a portal to the NASA/JPL Mars Exploration community, allowing students to interact with scientists and engineers and connecting them with past, current and future NASA and ESA Mars missions through forums, message boards and hyperlinks. The MDDES Web site also includes an extensive list of high school and middle school science opportunities, including camps, internships, and science fairs.

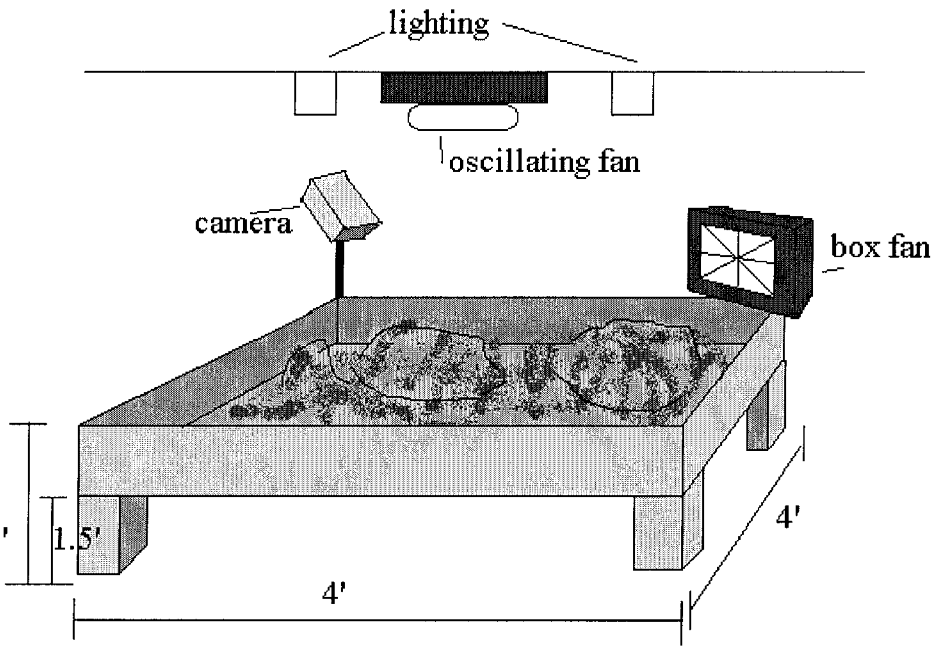

Figure 3. Schematic illustration of the basic features of the MDDES Martian landscape.

3.4 The Curriculum

The curriculum for the MDDES will incorporate many different branches of science and provide several interdisciplinary connections. Classroom activities are being developed to teach meteorology, comparative planetary science, physics, astronomy, computer science and engineering. Although some classroom activities will require the use of LEGO® robotics and ROBOLAB™, most do not, making the curriculum flexible for schools regardless of their resources. Mars Dust Devil Exploration Simulator activities will range from simple observations, such as counting of the number of dust devils, to advanced analysis using trigonometry and differential calculus to determine the instantaneous wind speed and direction. Thus, the MDDES curriculum will be suitable for students with a wide range of abilities. Eventually, students will be able to build and program their own rovers, to be "launched" to "Mars" through the U. S. mail or Federal Express.

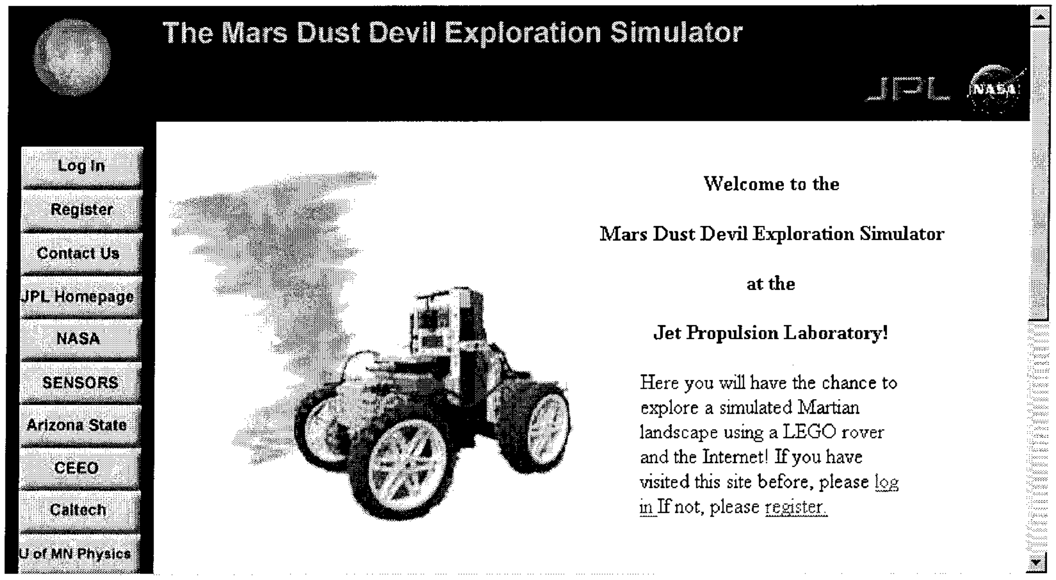

Figure 4. The homepage of the MDDES project.

The MDDES satisfies many of the National Science Education Standards [24]. The MDDES objectives address several of the Standards relating to science content, such as the understanding of mathematics, energy, the Earth system and the Solar System (Table 1). The design and data analysis activities involved in an MDDES mission address the Standards concerning scientific inquiry and the use of mathematics in the sciences (Table 2). The collaborative work associated with MDDES curriculum activities, submission of a mission to the MDDES server and analysis of the results satisfies the Standards encouraging students to work together and discuss the scientific implications of both the design and the results. Finally, several teaching Standards are addressed by the MDDES objectives (Table 3). The MDDES curriculum will be useful by teachers across the spectrum of grade levels. The activities provide motivation for the students to share the responsibility for their own learning and discuss their results with their colleagues.

The opportunities for interdisciplinary connections with the MDDES project are numerous. The impact of weather phenomena on culture, history, economics and society can be examined. Connections can be made between the weather phenomena studied in the MDDES curriculum and literature (e.g. Steinbeck's The Grapes of Wrath), film (e.g. The Wizard of Oz, Twister and Mission to Mars), history (the U.S. Dust Bowl of the 1930's), economics (The Great Depression), and social studies. Weather phenomena in the U.S. and around the world have substantially impacted human history, agriculture and prompted environmental conservation. Civil engineers address societal implications of weather phenomena by designing storm protection (e.g. the Galveston seawall) and rebuilding after storms. The controversy caused by some of these projects is an excellent case study in environmental science, political science and science policy. These issues could be addressed in the context of the MDDES.

Table 1. Alignment of the MDDES Content Objectives with the National Science Education Standards.

MDDES Content Objectives	National Science Education Standards
Physics Fundamentals: Angular Momentum, Gravity, Electrostatics, Thermodynamics	Develop student understanding of motion, forces, and transfer of energy, including interaction of energy and matter.
Meteorology and Hydrology of Earth and Mars	Develop student understanding of the structure of the Earth system.
Coriolis Effect, Cyclostrophic Wind Equation	Develop student understanding of energy in the Earth system.
Geology of Earth and Mars	Develop student understanding of the structure of the Earth system and the Earth in the Solar System.
Graphing and Measurement of Data	Use appropriate tools to gather, analyze and interpret data.
Trigonometry; Dust Devil Counts and Velocities	Use mathematics in all aspects of scientific inquiry.
History of Planetary Exploration	History of science; science as a human endeavor.

The MDDES project helps to prepares students for science in college and beyond with activities involving rover design, data analysis and collaborative work. Through the MDDES, students will learn how to formulate research questions, test hypotheses, evaluate designs, analyze results, think critically, rejoice in their successes and learn from their mistakes.

4. Progress and Current Status

The MDDES project is proceeding on limited funding. Funding from the SENSORS Project at Tufts University has provided for the training, time and equipment needed to construct the initial MDDES rover and Web site. Funding is currently being sought for construction of the Martian landscape, a Web-enabled permanent home for the project and integration and maintenance of the MDDES site. The permanent Uniform Resource Locator (URL) of the site will be announced when a permanent home is found for the site.

Table 2. Alignment of the MDDES Activities with the National Science Education Standards.

MDDES Activities	National Science Education Standards
Project Design and Research	Identify questions that can be answered through scientific investigation; design and conduct scientific investigations.
Design of Wind Sensors	Identify appropriate problems for technological design; design a solution or product.
Construction of Rover	Implement a proposed design; evaluate completed technological designs or products.
Collection and Analysis of Rover Data	Use appropriate tools to gather, analyze and interpret data.
Reporting of Results from Rover Data	Develop descriptions, explanations, predictions and models using evidence; communicate and defend a scientific argument.

Table 3. Alignment of the MDDES Teaching Objectives with the National Science Education Standards.

Teaching Standards	National Science Education Standards
Project Design and Research	Develop a framework of year long and short-term goals for students.
Design of Wind Sensors; Construction of Rover	Work together as colleagues within and across disciplines and grade levels.
Collection and Analysis of Rover Data	Challenge students to accept and share responsibility for their own learning.
Collection, Analysis, and Reporting of Results from Rover Data	Orchestrate discourse among students about scientific ideas.

The MDDES rover and Web site were designed, constructed and tested between June and September 2001. The design and testing of the anemometers is ongoing, and an example of the data obtained is shown in Figure 5. The downturn in the anemometer rotation values in Figure 5a is a result of the "end" of the dust devil pushing the anemometer in the opposite direction, marking the complete passage of the event. Future designs will attempt to reduce the wind resistance of the anemometer to prevent this behavior. The Martian landscape is currently being designed and may be constructed by students in the Explorer's Club at JPL in the near future. The server hosting the site is scheduled to go online in January 2002. The current Web site enables students to control the MDDES rover via the Internet, download prewritten programs, submit their own programs, view their data, and explore NASA and ESA Mars missions through the collection of hyperlinks on the MDDES Web site.

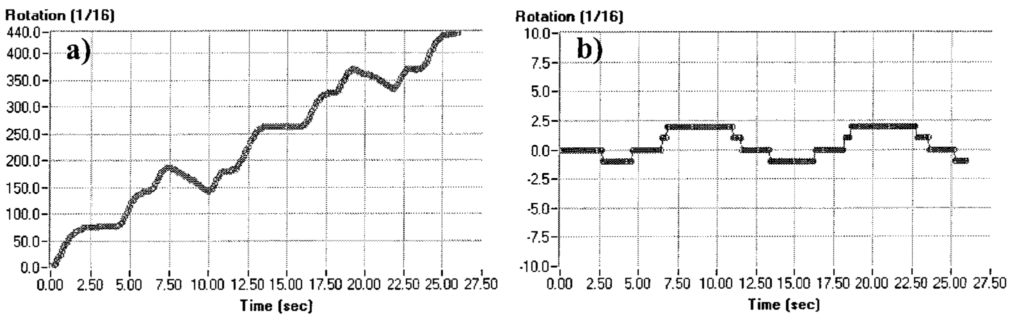

Figure 5. a) The total amount of MDDES anemometer rotation versus time and b) the direction of rotation.

The MDDES rover and software were tested in a New Hope, Minnesota fifth grade classroom in November 2001. The 25 students, of whom approximately 50% represented minority groups, responded with great enthusiasm and interest. The students obtained usable data and performed correct analyses of the results in a collaborative environment.

5. Future Work

Much work remains to be done. During the next two years, the curriculum discussed above will be developed and fully integrated into the MDDES Web site. Design of the curriculum for the MDDES will be lead by Arizona State University. A portion of the Web site containing message boards for student-student and student-professional interaction is also planned in which students can ask questions and solve problems online with each other and Mars scientists and engineers. Online chats between students and Mars exploration scientists and engineers are planned. Students will be able to launch their own rovers to the JPL through the U.S. Mail, Federal Express or other delivery services. The camera output from student missions will be recorded, allowing students and teachers to view their missions in MPEG or QuickTime format instead of as a series of still images.

Finally, the MDDES project will work with the NASA Mars Program and organizations such as the National Science Teachers Association and The Planetary Society to publicize the availability of the both MDDES and SENSORS projects. It is also hoped that the MDDES will become a component of the education and public outreach (E/PO) effort of the Mars Exploration Rovers (MER) mission, scheduled for launch in 2003, as well as future NASA missions to Mars.

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